Innovation-Based Learning: Enhancing Innovative Problem Solving and Higher-Order Thinking in Education through Multidisciplinary Collaboration

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Abstract

This paper introduces a method of using multidisciplinary teams to enhance levels of higher-order thinking and innovative problem solving within higher education. Traditional education methods may sometimes hinder the curiosity and inquisitiveness that drives innovation. For innovation to occur current knowledge must be questioned, solutions discussed, and ideas attempted and learned from regardless of success or failure in the outcomes. Our Innovation-Based Learning (IBL) framework provides students with both the freedom and responsibility to define their own learning within an environment that applies innovative thinking to current challenges. By assembling multidisciplinary teams, students are forced to rethink and reframe concepts that are familiar or dogmatic within their field but may be novel to teammates from other fields. As concepts are reexamined by the teams, new approaches may emerge as each student can contribute their individualized knowledge and skills towards a common innovative solution.

The following work presents and describes how the use of multidisciplinary teams enhances and fosters the development of innovative problem solving within an Innovation-Based Learning course. Within the course described, the learning objectives and deliverables of participants from both multidisciplinary teams and homogeneous teams (i.e. teams in which all members are from the same discipline) are reviewed and compared based on data collected from the course's online platform. A post-course survey was also administered to the students to gain insight and feedback on their opinions and interpretations of various aspects within the course. Questions relating to the research interests of this paper were analyzed and any noticeable trends inferred from the students' responses are described.

Introduction

The job market of the 21st century is filled with new challenges facing society, and students entering the workforce need to be prepared with the skills and knowledge required for success. Skills which industry and businesses are looking for include, but are not limited to, critical thinking, collaboration, adaptability, effective communication, and creativity [1]–[3]. These skills are commonly utilized when operating in the realm of higher-order thinking [4], [5] and are valued by employers because workforce needs are changing. As Steiner quoted from her findings by a business director in [2],

> "The place needs people who communicate well so they can assert a lateral idea because someone'll always say, 'No, it won't work'. You need to have communication skills and the confidence in a team environment to assert a different approach that might be the most innovative, but you have to drag the troops with you. How creative the organization is, is about balancing the need to get consensus from the team to move forward quickly with individuals expressing alternative views."

To make progress and advancements in society today requires a team of people knowledgeable in their individual disciplines, but willing to work collaboratively towards a common objective. Such efforts are often implemented in the workforce, but little is done in education to properly prepare students for working effectively on a multidisciplinary team. Bordogna states in [6],

> "As we move into the 21st century, however, the need to cross and mesh disciplinary boundaries is increasingly evident because new knowledge is increasingly created at disciplinary interfaces. In consonance, there is a growing need to influence academe to educate students to see the world whole, to help them sense the coupling among seemingly disparate fields of endeavor, to teach synthesis in balance with analysis, and to enhance their capabilities to build connections between the world of learning and the world beyond."

The education system is responsible for teaching the next generation of innovators who will take on society's current and future challenges. In order to properly prepare future innovators, the current educational environment must be altered [1], [6]–[9].

The Multidisciplinary Environment

Multidisciplinary courses, while beneficial, are only the tip of the iceberg so to speak. It is easy to open enrollment for classes to other departments, but students entering a multidisciplinary course will most likely have an entire educational upbringing taught in traditional classroom settings comprised of students in similar backgrounds [1]. The brick-and-mortar methods of traditional education, while beneficial for educating basic core materials, often do not provide students a pathway into the world of synthesis – more specifically innovation. For students to be successful in today's workforce they must acquire higher-order thinking skills alongside their understanding of basic concepts.

To get students operating at higher metacognitive levels educators must create an environment in which the students are confident and willing to share their ideas and knowledge [9]. It is only when communication starts, that diverse ideas can form. Once those ideas form, educators must take care to not stifle them and educate the students to do the same. New ideas are often confronted with criticism which quickly prevents any form of innovation [7]. Instead, instructors should direct students towards gaining a deeper understanding of the idea and push them to think innovatively and problem solve. On that note, however, instructors should not provide the students with too much order in the chaos as that hinders innovation. To provide too much order (i.e. constraints) reduces the critical thinking and problem-solving processes that a multidisciplinary environment is trying to promote [6]. It takes people willing to question current knowledge, push its bounds, and solve its problems for innovation to occur.

Another aspect in multidisciplinary courses is the multiple disciplines themselves. Communication can quickly cease if students are unable to learn and understand what their peers are saying. Instructors are generally experts in only one discipline, and so effectively teaching a group of students from various disciplines may require additional tools and resources. Instructors of such courses should not be expected to teach material outside of their discipline, but should instead act as guides for students, directing them towards tools for self-learning.

Innovation-Based Learning

The Innovation-Based Learning (IBL) framework was designed to create and encourage an innovative multidisciplinary learning environment [10]–[14]. The IBL model has been adapted into the curriculum at a research university within a cardiovascular engineering course. While the course is categorized under engineering, it is open to students from other colleges and departments as well; recent non-engineering participants have included pharmacy, animal sciences, and exercise physiology students. The course has also recently expanded to include students from a second university as well as online distance students that span four time-zones. Adding students from a variety of locations and disciplines has increased diversity among the students' educational backgrounds and interests (both as undergraduates and graduates). The diversity of the students' skills and knowledge fosters multidisciplinary collaboration within the course itself and enhances innovative problem solving as each student can offer their own resources and expertise to the class.

In this model, each student is responsible for proposing a potential team project guided by funding opportunity announcements (FOAs) from federal agencies such as the National Institutes of Health (NIH) and/or the National Science Foundation (NSF) that possess a cardiovascular influence [13]. Students then pitch their project ideas to classmates and form multidisciplinary collaborative teams that work together to find unique and innovative solutions to their chosen problem. Not only are students able to enhance their problem-solving skills, they also develop professional skills such as research, communication, team collaboration, and project management. ABET, an accreditation agency for engineering programs, lists the attainment of these skills under Criterion 3 for desired student outcomes which prepare graduates to enter professional practice [3].

Along with forming an innovative solution as a team, each student is also responsible for defining and demonstrating their own personal learning objectives. These learning objectives can be thought of as an individual plan-of-study as each student must acquire new knowledge and skills that contribute to their team's project. Each learning objective is logged and tracked on an online platform, which was designed by the authors [14]. The learning objectives must be clearly defined and have a deliverable (i.e. tangible proof or evidence of learning) that is representative of how in-depth the student wants to learn the objective. The depth of learning is classified using Bloom's Revised Taxonomy to allow learning to range from basic understanding to creation [4], [5]. Having the learning objective clearly outlined allows both the student and the instructor to know when an objective has been completed to the depth the student intended.

Mission

Upon successful completion of a pilot study utilizing IBL in a course the authors now want to verify such a model is indeed able to create an innovative multidisciplinary learning environment. Specifically, this paper looks to identify whether multidisciplinary aspects within teams played a role in enhancing innovative thinking as well as innovative student deliverables when compared to teams of homogenous discipline.

Methodology

Participants

During the semester in which IBL was implemented 35 students (both undergraduate and graduate) were enrolled in the course, 28 of whom gave permission to be in the study. Of those 28, 6 were female and 22 were male. The mix of disciplines enrolled in the course consisted of 9 students from Electrical Engineering, 4 from Computer Engineering, 5 from Mechanical Engineering, 9 from Biomedical Engineering, and 1 student from Health, Nutrition and Exercise Sciences.

Online Platform

Students were required to log and maintain their learning objectives using an online platform. Upon completion of a learning objective, students were responsible to create links to their evidence of learning and deliverables. Such evidence included, but was not limited to documents, videos, presentation updates, papers, patents, outreach activities, etc. Collecting these digital artifacts on the online platform allowed instructors to view each student's learning objectives as well as their provided deliverables.

The authors were interested in determining whether multidisciplinary collaboration led to more innovative student deliverables within the course. Each of the student teams were rated with a multidisciplinary score based on how many different disciplines made up the team (e.g. a homogenous team of students from only 1 discipline would receive a score of 1, a team that included 3 Electrical Engineers and 1 Mechanical Engineer would receive a score of 2). The higher the multidisciplinary score, the more diverse the team's members were in disciplines. Table 1 depicts the multidisciplinary scores of the 9 student teams based on team members willing to participate in the study. It should be noted that some teams may have received a lower multidisciplinary score due to additional students on those teams who did not consent to participate in the study, as shown in Table 1. A brief description of what each team collectively developed for their project is also provided. Precise details of the students' projects are not able to be disclosed as they are the intellectual property of the students.

Student deliverables were assessed and compared between each of the teams. Assessment of the innovation of the deliverable was based on the level of its external value (i.e. how much impact it held in reference to individuals not enrolled in the course). The quantification of how much external value a deliverable possessed was based on two factors: 1) the method in which the deliverable was or will be presented to others (e.g. in-class presentation, conference presentation, published, etc.) and 2) the level at which the deliverable received or will receive review (e.g. peer review, non-expert review, expert review, etc.).

Team	Total # of Students in Group	# of Students Participating in Study	Multidisciplinary Score of Team	Summary of Project Deliverables
A	2	1	1	Designed Custom Hardware and a Software Algorithm
B	5	4	2	Designed a Website
C	4	3	2	Designed Custom Hardware and a Software Algorithm
D	4	4	2	Designed a Software Algorithm for Off-the-Shelf Hardware
E	5	4	2	Designed Custom Hardware and a Software Algorithm
F	6	4	3	Designed Custom Hardware and a Software Algorithm
G	4	3	2	Designed a Software Algorithm for Off-the-Shelf Hardware
H	4	3	1	Designed a Promotional Pamphlet
I	3	2	2	Designed a Website

Table 1: *Each student team was assigned an arbitrary identification letter (A-I). Depicted are the total number of students that participated in the group as well as the number of members who agreed to be a part of the study. Based on the diversity of the team members' degree programs, each team was assigned a Multidisciplinary Score (only the students who consented to participate in the study were used in determining the score). A team's score is equal to the number of unique degree programs represented on the team. A brief description of what the team collectively developed is also provided, precise details of the projects are unable to be*

For a deliverable to have external value it must contain some level of importance or provide benefit to individuals external to the course. Quantifying the deliverable based on the method in which it is presented to others helps determine: 1) who is impacted by it and 2) how extensive the impact will be. Examining the level of review the deliverable received helps determine whether it is important or beneficial to those it impacts. Reviews by experts are of higher caliber than reviews by peers, due to their depth of knowledge. Experts are assumed to be very knowledgeable in their subjects, and so, expert reviews stating the deliverable is beneficial are taken as prima facie evidence of high value.

For example, suppose Team A and Team B both provide a poster as a deliverable. Team A presented their poster at an outreach event at a local high school to promote STEM fields. Prior to presenting, the poster was reviewed by an outreach coordinator at the high school. Team B presented their poster at a conference known for research in the subject. Prior to presenting, the poster was reviewed by 3 conference reviewers. While both teams presented to external audiences, the deliverable of Team A would have lower external value than Team B. Team A presented to an audience that most likely lacked prior knowledge of the subject and they received only 1 non-expert review making it difficult to determine whether the poster contained any added benefit to the audience. Meanwhile, Team B presented to an audience with prior subject knowledge and received 3 expert reviews on their poster's content, thus it can be assumed the poster adds value to the subject area and has added benefit to the audience.

To maintain consistency across the teams, assessment of deliverables that contained some level of external value and contributed towards the team's overall goals were evaluated by the authors for this paper. Each of the deliverables was then given an innovative impact score based on its level of external value. The innovative impact score is used to represent how impactful the students' innovative solution was to others, while also representing the extent of innovation that went into the derived solution. Higher innovative impact scores indicate more extensive research, design, and review went into the team's innovative solution. Details of that scoring are provided below:

- 1 – Impacts at the group/team level
  - *e.g. Peers, Class, Research Group*
- 2 – Impact at the college level
  - *e.g. Organizations, Departments, College Symposiums*
- 3 – Impact at the academia level with limited reach
  - *e.g. Small Conferences/Symposiums, Publishes in conference proceedings*
- 4 – Impact at the academia level with extensive reach
  - *e.g. Large Conferences, Publishes in journals*
- 5 – Impacts society or the consumer market
  - *e.g. Patents, Start-up Companies, Business Launches*

Each team's deliverables were then graphed in comparison to the deliverable's innovative impact score to clearly compare the innovation of each team, see Figure 1. When cross referenced with Table 1 the authors can analyze if teams with higher multidisciplinary scores also had increased innovation.

Post Course Survey

A post-course survey was provided to the 35 enrolled students, 24 of whom chose to participate and completed the survey in its entirety. It should be noted that the students who chose to complete the survey were not necessarily the same students who chose to participate in the study by sharing their learning objectives and deliverables on the online platform. The survey contained 26 questions that were analyzed by the authors to gain insight and feedback on the students' opinions and interpretations of various aspects within the course. Of the 26 questions, 9 were pertinent to the multidisciplinary research questions discussed in this paper. Other questions of the survey related to the use of software tools, team formation, student interactions, and students' perceptions of their learning growth and course experience. The 9 questions pertinent to this paper and their details are listed below:

- Q6: Does your team have members from different majors or programs?
  - *Yes/No Response*
- Q7: If yes, what advantages did that provide?
  - *Free Response, only answered by students in multidisciplinary groups*
- Q8: If yes, what disadvantages did that introduce?
  - *Free Response, only answered by students in multidisciplinary groups*

- Q9: Based on your experiences, what is the greatest challenge for effective communication between team members?
    - *Free Response*
- Q10: I feel the collaboration within my team was successful when working together towards our learning objective(s).
    - *5-Point Likert Response (strongly agree to strongly disagree)*
- Q11: I feel that my groups learning objectives were achieved.
    - *5-Point Likert Response (strongly agree to strongly disagree)*
- Q12: I feel the deliverable(s) my team achieved are appropriate for our defined group learning objectives.
    - *5-Point Likert Response (strongly agree to strongly disagree)*
- Q13: I feel that my personal learning objectives were achieved.
    - *5-Point Likert Response (strongly agree to strongly disagree)*
- Q14: I feel the deliverable(s) I personally achieved are appropriate for my defined learning objectives.
    - *5-Point Likert Response (strongly agree to strongly disagree)*

Questions 6 through 8 were used by the authors to gain insight into the advantages and disadvantages which multidisciplinary aspects had on the team from the student's perspectives. Question 9 was used by the authors to see if any students felt multidisciplinary aspects created challenges for effective communication among team members. Assessment of these questions was done by analyzing the responses for common themes (see Tables 3 and 4).

Questions 10 through 12 were used to gain insight on the students' views of their team's success or failure at collaboration and whether they deemed their teams learning objectives and deliverables appropriate for their team goals. Questions 13 and 14 were used to gain insight on whether the student's deemed their personal learning objectives and deliverables appropriate for their desired goals. Comparisons for questions 10 through 14 are made between the answers from students in multidisciplinary groups (based on those who answered yes in Q6) and those of students in homogenously disciplined groups.

Results

Online Platform Data Results

The students provided a wide variety of deliverables that were categorized into 10 common categories. Two of these categories (Refereed Conference Attendance and Refereed Conference Presentation), as shown in Figure 2, occur twice and are separated by :1 and :2. This is due to some team's participation in two separate events that fell under the same category but needed to be distinguished separately in order to maintain a correct evaluation of the deliverable's innovative impact score shown on each section of the bar plot (using the rating of 1 to 5 discussed previously).

Using Table 1 the authors were then able to relate a team's multidisciplinary score to the team's overall innovative impact score using Figure 1. Table 2 shows the comparisons. It is interesting to note from Figure 1 that of the 23 provided student deliverables 13 had an innovative impact score of 3 or more. The 13 deliverables that contained a 3 or more were implemented by 5 of the

9 student groups, which means about half of the student groups produced deliverables that were presented and reviewed by individuals external to the university.

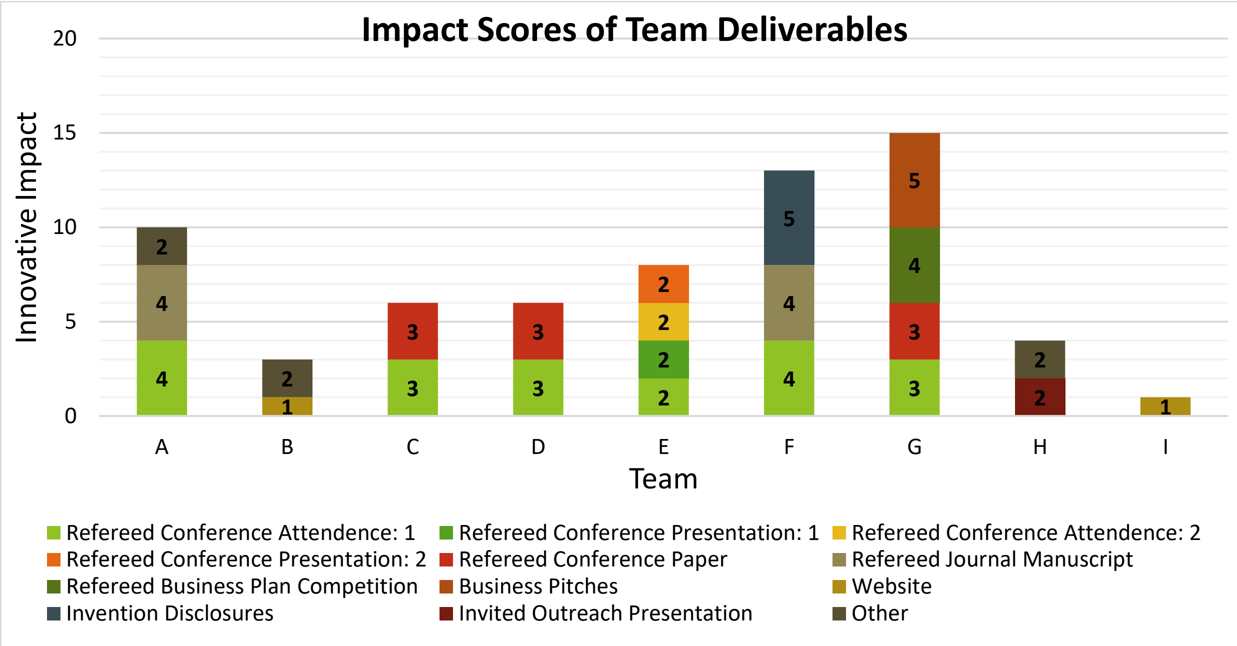

Figure 1: *Graphical depiction of team deliverables showing each deliverable's innovative impact (scoring from 1 to 5, details found in the methodology). Each team's overall innovative impact can be determined by summing the innovative impact for all individual deliverables provided by the team. Higher innovative impact scores represent student deliverables that provided greater external value (i.e. how much impact it held in reference to individuals not enrolled in the course) and required more extensive research, design, and review processes.*

Team	Multidisciplinary Score	Innovative Impact
A	1	10
B	2	3
C	2	6
D	2	6
E	2	8
F	3	13
G	2	15
H	1	4
I	2	1

Table 2: *Relationship between the team's determined Multidisciplinary Scores and overall Innovative Impact Score*

As shown in Table 2, Team F had the highest multidisciplinary score of the 9 teams and were also one of the top-ranking groups for innovative impact. Team G had the highest innovative impact of all the groups and had a multidisciplinary score of 2. Team A also had a high innovative impact score compared to most groups but had a multidisciplinary score of 1. The only other team to have a multidisciplinary score of 1 was Team H which received an innovative impact of 4, which was one of the lower impact levels. Team I had the lowest innovative impact score of 1 but had a multidisciplinary score of 2.

From the results shown in Table 2, it is difficult to see any distinct trends amongst the teams. In general, the results seem to suggest that multidisciplinary aspects tend to increase innovative impact within the teams, but that is not always the case as Team A demonstrates. Then again, Team A may have had multiple disciplines on the team, but not all students were willing to be in the study, therefore results could be affected. Additional studies should be performed with a larger group of participants before any suggested trends can be concluded.

Survey Results

Free Response Question Results

Question 6 of the survey directly asked students if their group contained members from other disciplines, therefore allowing the authors to decipher between students from homogenous and multidisciplinary groups. Results of the yes/no responses showed that 14 students responded with yes and 10 with no. The 14 students that were part of multidisciplinary groups were then asked additional questions related to the advantages and disadvantages of being in a multidisciplinary group. Of the 14 students only 13 chose to answer the additional questions. The results of student's free responses were analyzed for general themes and are shown in Table 3.

Q7: If yes, what advantages did that provide?		
Common Themes	*# of Responses*	*Quotes from the Students*
Provided skills, perspectives, knowledge, and expertise needed for group goals	12	"It provided a wider spread of knowledge that could lead to solving problems differently." "This presented a good mixture of skills, allowing each person to focus his contribution to the project in an area that aligned with his strengths."
Needed for project success	2	"Allowed us to complete each aspect of our project successfully (Hardware design, Software, Mechanical)"
Increased networking options	1	"It also opened a few doors for us through our more diverse connections."
Increased personal learning growth	1	"I as an undergraduate student learned a lot from my team members who were graduate students/distance students."
Q8: If yes, what disadvantages did that introduce?		
Common Themes	*# of Responses*	*Quotes from the Students*
Increased communication barriers	7	"Team members had to learn outside of their field to push the project forward. While beneficial to a student, there is a real cost to keeping up to speed, as well as a communication barrier until a level of working knowledge is attained."
Difficulties meeting or scheduling with the group	2	"The geographical differences of each of our team members made it difficult to communicate and collaborate."
Hindered project progress	3	"At times we got hung up on different aspects of the project that only specific members were qualified to work on so it led to some slowdowns in the process that wouldn't have been present if we had the same backgrounds."

Table 3: *Evaluation and results of free response questions answered by students that were part of a multidisciplinary team.*

After analyzing the students' responses to the advantages of being in a multidisciplinary team 4 common themes were noted. The most common theme, which was mentioned by 12 of the 14 students, related to the benefits in having increased skills, perspectives, knowledge, and expertise amongst the group that could be utilize towards the team's learning objectives. Another theme that was mentioned by 2 of the 14 students discussed that multidisciplinary aspects were needed for success in completing the team project due to the different subject areas related to the project. Other interesting aspects that were mentioned by 1 of the 14 students related to increased networking that occurred due to the multidisciplinary aspects of the team. One student also mentioned personal learning growth occurred from the multidisciplinary aspects of the team due to the student's team members being graduate students or distance students.

The responses to the disadvantages of being in a multidisciplinary group showed 3 common themes. The most common theme, mentioned by 7 of the 14 students, discussed that multidisciplinary aspects increased communication barriers between group members due to the lack of background knowledge. Students, overall, found it difficult and frustrating to communicate their ideas and/or progress to group members because they would have to explain things in detail for their group members to properly understand the discussion. Another theme mentioned by 2 of the 14 students related to difficulties meeting as a group due to distance or conflicts in schedules. The third theme discussed by 3 of the 14 students mentioned that multidisciplinary aspects within the group hindered project progress.

Evaluating the results of questions 7 and 8 show conflicting views. The responses to question 7 suggest that multidisciplinary collaboration is crucial for promoting innovative thinking due to the various perspectives and knowledge it brings together. However, results from question 8 suggest that multidisciplinary collaboration also complicates the sharing of such skills and knowledge because of communication barriers between disciplines. So, while beneficial for bringing together ideas and perspectives, multidisciplinary aspects within collaboration can also be problematic for cultivating innovative thinking if students are not able to overcome communication barriers. The ability to communicate effectively in a collaborative environment are skills that industry wants students to be capable of when entering the workforce. The fact that students are noting this as being a difficult and frustrating experience demonstrates that they were not proficient in these skills prior to taking this course. The authors found this feedback enlightening as it shows that the IBL model is effectively educating students to learn these valuable skills despite it being a frustrating and difficult experience for them.

All students (from both multidisciplinary and homogenous groups) were then asked to answer Question 9. The free responses provided perspectives on what students viewed as being the greatest challenge for effective communication between team members. Of the 24 students to complete the survey 19 chose to provide an answer to this question. Of the 19 who answered, 13 were from multidisciplinary groups. The responses of all 19 students were analyzed for common themes and are shown in Table 4.

The student's responses to question 9, showed 7 common themes. The most common theme mentioned by 8 of the 19 students related to scheduling meetings with group members. The second most common theme discussed by 5 of the 19 students related to the need for timely communication and updates amongst team members, without it progress on the project was often hindered. 4 of the 19 students felt working together as a group was the greatest challenge for effective communication; bringing everyone's interests towards a common goal or being able to mitigate group conflicts were commonly mentioned by students in relation to this theme. Other themes that were stated by 3 of the 19 students included working individually on a task before updating the group, overcoming communication barriers within the group, or the varying geographical locations of group members. Some interesting responses that were provided by 2 of the 19 students were placed under the theme of building group confidence; specific statements related to trust and open communication among group members as well as being able to receive critique.

Q9: Based on your experiences, what is the greatest challenge for effective communication between team members?		
Common Themes	*# of Responses*	*Quotes from the Students*
Scheduling meetings	8	"The greatest challenge for effective communication in my opinion is the balancing of the time and schedules of individual students as everyone has other groups and work to do as well."
Timely communication and updates	5	"Timely communication so that the rest of the team knows there is a roadblock." "At times, communication frequency was reduced to one-send, one-receive per day."
Working together as a group	4	"Bringing everyone on the same page with desired goals within the set time constraint for the project in play" "The capacity to manage conflicts or disagreements between team members."
Working individually on tasks	3	"Working individually and coming together as a group to discuss what progress we made"
Overcoming communication barriers and/or lack of knowledge within the group	3	"At times it can be difficult to communicate progress with different team members that have different backgrounds as they might not have the same knowledge about what goes into the different processes."
Varying geographical locations	3	"Based on my experiences with this project, the greatest challenge was the difference in geographical locations between our group members."
Building group confidence	2	"Building trust and open communication without being physically near" "The ability to receive critics from other teammate members."

Table 4: *Evaluation and results of free responses to question 9 answered by all students willing contribute.*

Amid all the common themes, multidisciplinary aspects are most notable in the responses discussing communication barriers and working together as a group. These responses were interesting to note as they are very similar to the responses provided as being a disadvantage of working with multidisciplinary groups; with communication barriers being a large influence on team progress and understanding.

5-Point Likert Scale Question Results

Questions 10 through 14 were used to gain insight into student perspectives of their team success or failure as well as the student's personal insight into individual success or failure. Of the 24 students to complete the survey all 24 students provided an answer to each of these questions, with an exception to question 10; one student from a homogenous group did not provide an answer to this question bringing the total answers to 23. Of the 24 students to answer these questions 13 were from multidisciplinary groups and 11 were from homogenous groups (except for question 10 in which there were 10 students from homogenous groups). The results show the responses of students in multidisciplinary groups compared to those of students in homogenous groups.

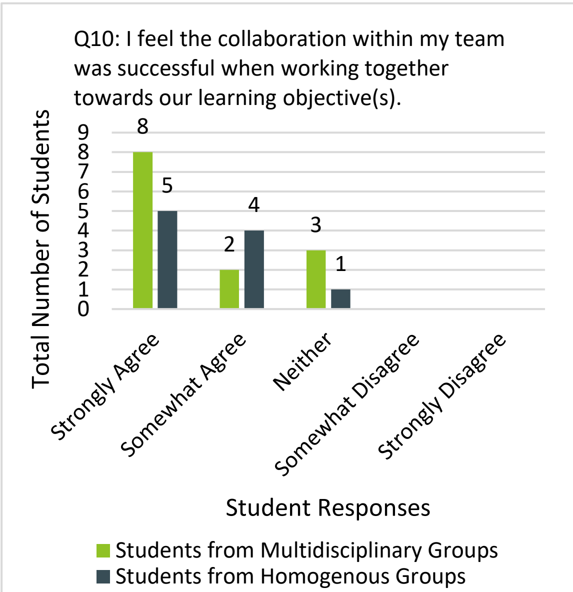

Figure 2: *Comparison of collaboration success of multidisciplinary groups and homogenous groups based on responses to post-course survey.*

Questions 10 through 12 of the survey specifically look at the success or failure the students perceive from the viewpoint of the team. Overall, the results, as depicted in Figures 2 – 4, show that students believed their team (both multidisciplinary and homogenous) was successful when it came to team collaboration (Q10), achievement of learning objectives (Q11), and providing appropriate deliverables for the team learning objectives (Q12).

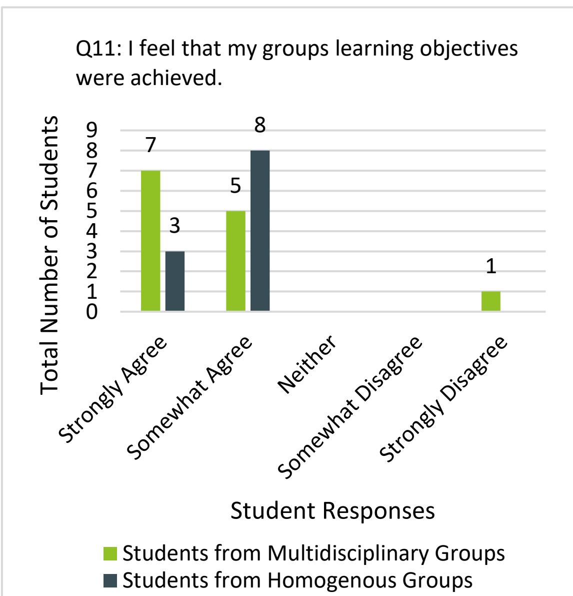

Figure 3: *Comparison of learning objective achievement of multidisciplinary groups and homogenous groups based on responses to post-course survey.*

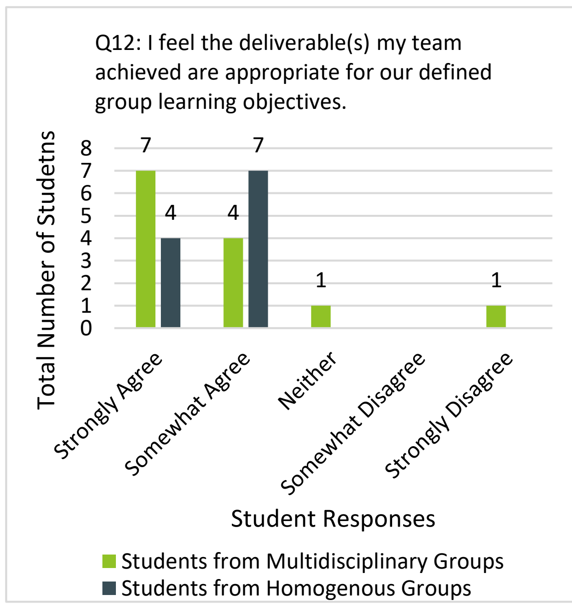

Figure 4: *Comparison of deliverable achievement of multidisciplinary groups and homogenous groups based on responses to post-course survey.*

It is interesting to note that for all questions most students in multidisciplinary groups chose "strongly agree" when asked about their team's success in each category, while most students in homogenous groups chose "somewhat agree" when asked the same questions

This drove the authors to question why multidisciplinary groups feel more strongly about their group's success than homogenous groups? A possible reasoning, suggested by the authors, is that multidisciplinary groups have the advantage of being able to task individual portions of the project based on member expertise which may impact the group's ability to advance the project quickly and successfully. Contrarily, homogenous groups would have to account for lack of expertise and task individual members to learn and gain knowledge in an area unfamiliar to them which may hinder project success.

Questions 13 and 14 of the survey specifically look at students' perspectives of their individual success or failure at achieving their own learning objectives (Q13) and providing appropriate deliverables for their personal learning objectives (Q14). Overall, the results, as depicted in Figures 5 and 6, show that most students (from both multidisciplinary groups and homogenous groups) felt they were successful in achieving their personal learning goals and provided deliverables they deemed appropriately represented their learning.

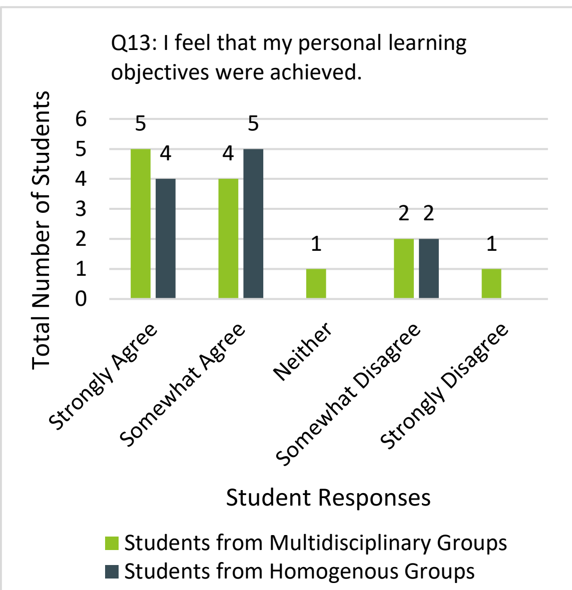

Figure 5: *Comparison of personal learning objective achievement of students in multidisciplinary groups and homogenous groups based on responses to post-course survey.*

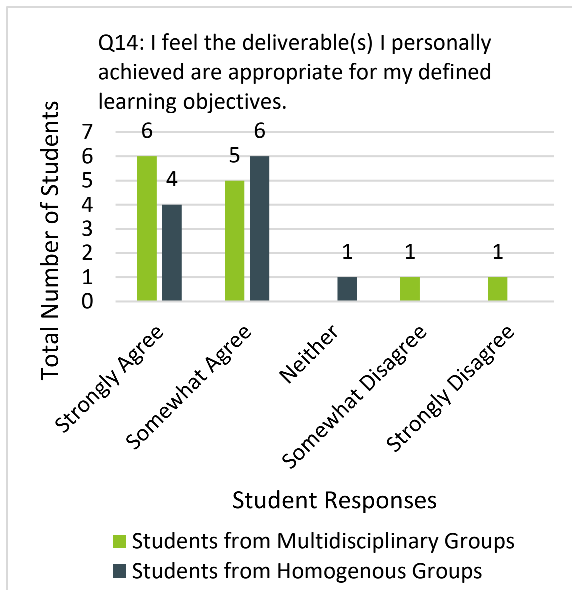

Figure 6: *Comparison of personal deliverable achievement of students in multidisciplinary groups and homogenous groups based on responses to post-course survey.*

It is of interest to note the similar trend previously discussed in questions 11 and 12 reoccurs in these questions. Most students from multidisciplinary groups chose "strongly agree" when asked about their individual success in each category, while most students from homogenous groups chose "somewhat agree" when asked the same question. While the variances of the results are not nearly as abrupt as the trend seen in questions 11 and 12, it is insightful that a similar trend is occurring in the student's responses from a team perspective as well as an individual perspective.

Discussion

Interpreting Results

The results discussed in this paper pertain specifically to multidisciplinary collaborative student groups and the potential influence multidisciplinary aspects may have on student innovation. From the online platform data, results are suggestive rather than conclusive due to the small number of participants and lack of multiple cohorts. While definite conclusions cannot be drawn, there are indications that an increase in multidisciplinary elements, when used in collaborative efforts, has the potential to increase innovative outcomes if the team is organized and communication issues are minimized.

From the survey, the open response questions informed the authors that while multidisciplinary collaboration is beneficial for integrating ideas and skills it also provides a barrier for communication amongst the group that, if not overcome, can hinder overall project success. Despite the communication barriers, results of the survey also show that approximately half of the students on multidisciplinary teams chose "strongly agree" in categories relating to success of their team's collaboration, objectives and deliverables (Questions 10, 11, 12) with an overall majority of the responses being successful in nature (selecting either "strongly agree" or "somewhat agree"). This indicates that most of the students in multidisciplinary groups were able to overcome communication issues previously described. It can be further be assumed that once effective communication was established, students could develop a group environment that allowed them to work together to devise an innovative solution to their chosen problem. In other words, multidisciplinary communication was within these students' zone of proximal development. These results suggest that implementing IBL into the course curriculum encouraged students to learn and apply core skills that ABET looks for as outcomes in prepared graduates. Such outcomes include, but are not limited to, the "ability to function effectively on a team, create a collaborative and inclusive environment, develop and conduct appropriate experimentation, and analyze and interpret data" [3].

Improvements and Future Directions

As suggested by the results, a critical factor that must be addressed amongst all students in future iterations of IBL is team communication. Communication barriers between team members for understanding of concepts (especially in multidisciplinary teams); timely communication (in relation to updating the team); and communication of group objectives (being able to work collaboratively and effectively) were all common issues mentioned by the students from their collaboration experiences.

While students found these problems to be frustrating, communication is one of the skillsets industries look for and is something the IBL model is attempting to educate to the students. The fact students are mentioning their frustrations with communication problems is informational as it shows the model is imposing valuable learning situations upon the students. Beneficial as it may be for the students to overcome these difficulties by themselves, additional support can reduce complications in the learning experience. Future directions within the IBL model would include additional support tools for project management and communication that would not only be provided to the students but demonstrated as well, so students learn to use the tools effectively. Additionally, more informative instructor feedback provided at increased intervals may allow for quicker problem management and lessen frustrations related to communication difficulties in future iterations of the course. Plans to incorporate and implement these improvements are being discussed for future semesters utilizing the IBL model in course curricula.

Conclusion

Overall, the authors feel the pilot study of the IBL model in the cardiovascular course was a success as students were able to effectively innovate solutions to their chosen projects. While the incorporation of the IBL model was successful, it was not without its problems. Communication was found to be an overall key factor to the student's success and, if not overcome, it inevitably hindered a student's progress in the course. Despite the challenges the students faced with IBL, most students had great success and learned valuable skills from the experience. While not conclusive, results of this paper do suggest that incorporating the IBL model into curriculums has the potential to foster a multidisciplinary collaborative environment that is beneficial to cultivating innovative learning. With future improvements, Innovation-Based Learning may be a solution for educating the next generation of innovators.

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